§8. Effect of Fluctuations of Laser Frequency on Accurate Phase Measurement

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The FIR laser interferometer measures the phase change due to the plasma density by heterodyne technique. Fluctuations of the frequencies of main and local lasers affect the phase measurement. When the frequencies fluctuate, the phase fluctuates due to the difference in optical path length or dispersion in electrical circuit. The stability of the frequencies are measured, and resultant phase error is estimated.

Figure 1 shows the schematic drawing of the FIR laser interferometer for LHD. Optical path lengths are also indicated. The beat frequency of main and local lasers are stabilized to be 1MHz by an analog feed-back control.

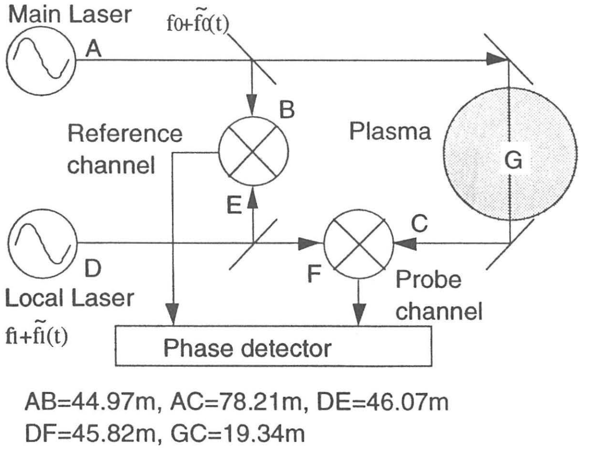

Fig.1. Schematic drawing of the FIR laser interferometer.

The beat frequency is measured by a counter, and the resolution of the measurement is about 0.1 kHz. The beat frequency has the following three components: (i) fast fluctuations with the frequency of 3.8Hz and about 2 kHz peak to peak amplitude; (ii) slow fluctuations with the frequency of about 0.05 Hz, which is caused by a small back talk of the main laser to the local one; (iii) rapid frequency change due to the analog feed back control, which occurs when the beat frequency reaches the control boundary of ±5kHz (Fig.2). Since the feed back system control also the power of the main laser, the absolute frequency is controlled to be in the range of about ±5kHz.

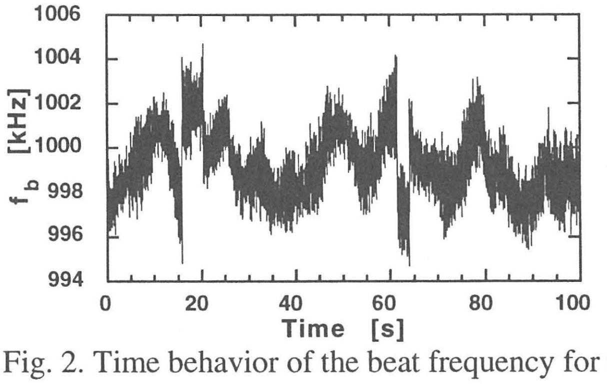

Fig. 2. Time behavior of the beat frequency for the case of feed back control.

The two mixers or phase detector measure the phase difference of their two outputs. Since the optical path is free space or oversized waveguide, which is almost free space from the viewpoint of group delay, the phase at points B, E, F are the time delayed phase at points A, D, D, respectively. The phase at point C is the summation of the delayed phases of point A and G(plasma). The measured phase of the output of the phase detector can be written as

$$\phi_{meas}(t) = \phi_{probe}(t) - \phi_{reference}(t)$$
$$= \phi_{offset} + \Delta\phi_{path}(t) + \phi_{plasma}(t - \tau_G),$$

where ϕ_{offset} is constant offset of the phase, and $\Delta\phi_{path}(t)$ is the phase error due to the difference in optical path lengths. τ_G is the delay in GC. The error is written as

$$\Delta\phi_{path}(t) = -2\pi\tilde{f}_0(t) \times \Delta\tau_{CB} + 2\pi\tilde{f}_1(t) \times \Delta\tau_{FE}$$
$$\approx 2\pi \times (5[kHz] \times 0.1[\mu s] + 5[kHz] \times 0.001[\mu s])$$
$$\approx 2\pi \times \frac{1}{2000},$$

where $\Delta\tau_{CB}$, $\Delta\tau_{FE}$ are the difference in the delay times of optical paths AC, AB, DF, DE. The error is estimated assuming the frequency fluctuations are 5kHz. The estimated error is much smaller than the resolution of the phase detector, and the error is negligible in experiments.